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ARTICLE

An evaluation of low-level automation navigation functions upon vessel traffic services work practices

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Abstract
The Sea Traffic Management (STM) Validation Project is a European-based initiative with ambitions to improve maritime safety and efficiency through information sharing in real time. The purpose of this paper is to evaluate the "STM services," which can be categorized as low-level automated functions designed to improve information exchange between ship and shore. Full-scale simulated scenarios were developed and tested on 16 professional vessel traffic service (VTS) operators comparing VTS operations as they are today with the added STM functionality. Data collection involved observations which assessed the frequency and type of interactions between ships and VTS, followed by questionnaires to provide an overall assessment of the user experience. The results indicate that the frequency and method of communication patterns between VTS operators and ships will be affected by the integration of the STM services. Additional access to navigational information could change the role of VTS operators in traffic situations compared with traditional operations. This paper discusses the findings from a socio-technical systems perspective while also addressing the individual STM services and their potential impact on VTS operations. This research provides valuable information for European VTS centers that could be affected by the implementation of e-Navigation and, specifically, the STM services.

Keywords E-Navigation · User experience · Technology integration · Vessel traffic services · Socio-technical system · Workload

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1 Introduction

The maritime industry is a complex socio-technical system made up of people, tasks, organizational structures, and technologies which are all interrelated (Leavitt 1965; Praetorius 2014; de Vries 2015). In maritime operations, ship and shore-based operators work together, amid different tasks and work structures to achieve common safety and regulatory goals (Costa et al. 2018a, b). Introducing change to any aspect of a socio-technical system will have consequences on other parts within the system; for example, the introduction of new technologies will have an impact not only on the technology users but also the organization and processes of work design and the regulatory environment. Over the past decade, the concept of e-Navigation and the "connected ship" has dominated the maritime industry (International Maritime Organization 2014; Costa et al. 2018a, b). The International Maritime Organization (IMO) has defined the scope of e-Navigation as "the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment" (International Maritime Organization 2014). This means finding digital solutions and implementing new technologies to solve complex problems (i.e., safety, efficiency, connectivity, transparency) in the maritime industry. To fully understand the impact of e-Navigation services, it is important to embrace a systems approach and to understand the outcomes or consequences upon the socio-technical system (Costa et al. 2018a, b).

Research on technological changes and the impact on maritime work practices including navigational aids have been ongoing for many years (Lützhöft 2004; Aichhorn et al. 2012; Mallam and Lundh 2016; van de Merwe et al. 2016; Costa et al. 2018a, b; Man et al. 2018). Outcomes of several European Union (EU) projects have specifically addressed various aspects of the e-Navigation concepts and proposed solutions (i.e., MarNIS (2004-2008), ACCSEAS (2007-13), (MONALISA (2010-EU-21109-S), MONALISA2.0 (2012-EU-21007-S), EfficienSea2 (H2020-EU.3.4), STM (2014-EU-TM-0206-S)) and the potential impact on the socio-technical system of shipping. The benefits of increased connectivity and improved access to information should help increase efficiency, promote information transparency, and improve maritime operations. However, the exponential increases in technology have also raised concerns related to potential risks associated with increased complexity on the ship's bridge and to vessel traffic services (VTS) (van Breda and Passenier 1998; van Breda 2000; Porathe et al. 2012; Praetorius 2014; Praetorius et al. 2015a, b; de Vries 2017; Costa et al. 2018a, b). These technologies not only offer digital solutions, but they also change work practices and organization within the maritime industry. This paper will focus on the impact of specific e-Navigation services on VTS systems and operators.

1.1 The role of vessel traffic services

As defined by the IMO in Resolution A.857(20), the VTS is a "service implemented by a Competent Authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment. The service should have the capability to interact with the traffic and to respond to traffic situations developing in a VTS area" (International Maritime Organization 1997). VTSs are shore-based stations which provide a range of services to ships, from the provision of simple information related to traffic or meteorological hazard warnings to extensive management of traffic within a port or waterway (International Maritime Organization 1997). In terms of governance, IMO Resolution A.857(20) provides guidelines and criteria for VTS operations which are associated with SOLAS Regulation V/1/7/02; however, there is no international regulation governing the design and operation of a VTS leading to national differences in how VTSs are organized (IALA 2016) (Brodje et al. 2013). These national differences include varying levels of authority and service provisions. In an attempt to standardize these differences, the IALA VTS Committee provides the most current and accurate information related to VTS operations, technologies, and VTS training (IALA 2016). However, in January of 2020, the IMO's Sub-Committee on Navigation, Communication and Search and Rescue (MSCR 7) met and discussed the IMO-VTS guidelines and will soon revise the IMO Resolution A.857(20) (IMO 2020).

VTS offers three different levels of services: information navigational service (INS) which supplies information to all participating vessels within the VTS area, e.g., general traffic information; traffic organization service (TOS) which is concerned with the traffic operations, e.g., ship maneuvers, access areas or speed limits; and navigational assistance service (NAS) which provides information for the navigation task, e.g., own position relative to obstacles (International Maritime Organization 1997, Praetorius et al. 2012). Trained VTS operators (VTSO) monitor the traffic in real time and obtain information from various sources including VHF radio communications, radar and AIS, weather sensors and reports, navigational warnings and instructions from Maritime Authorities and Port Authorities (IALA 2016). A VTSO uses this information, in addition to their experience and knowledge, to generate an overview of the VTS area and traffic image. The VTSO can then contact the vessel via VHF radio to provide information or assistance to a vessel in the area, as deemed necessary (e.g., assistance in transfer through a narrow passage). The time between when the VTSO observes a potentially dangerous situation and when they establish contact with the vessel in danger is relatively short, often a few minutes or less (Praetorius 2014).

1.2 Vessel traffic service research

VTS work practices have been the topic of many studies over the past 20 years (Baldauf and Wiersma 1998; Harre 2000; Nuutinen et al. 2007; Brödje et al. 2010; Brodje et al. 2013; Praetorius 2014; van Westrenen et al. 2014; Praetorius et al. 2015b; de Vries 2017; Costa et al. 2018a, b). Early VTS research focused mainly on the technical side of operations, including the reporting and monitoring of vessels, starting with the introduction and installation of AIS on board ships (Baldauf and Wiersma 1998; Harre 2000; Chang 2004). Communication and information exchange have consistently been cited as key factors for safe and effective traffic management and navigational assistance (Chang 2004; Brödje 2012; Costa et al. 2018a, b).

Situation awareness (SA), a person's internal (mental) model based on the perception of environmental elements and events with respect to time or space, the comprehension of their meaning, and the projection of their future status, has been another focus area of VTS research (Endsley 1995). The most comprehensive research was completed by Weirsma and colleagues, which used the methodology developed by Endsley to assess and measure SA of VTSOs in Rotterdam and Helsinki (Endsley

1995; Wiersma 2010). Findings from this work concluded that in order to provide effective assistance to vessels, operators need to obtain and maintain situation awareness on all three levels (Wiersma 2010). Additionally, it was concluded that communication between VTS and traffic is regarded as a direct measure of VTSO performance and an indirect measure of SA (Wiersma 2010). Altering the current means of communication or interaction with new technologies may disrupt these work practices and performance measures.

Brödje et al. (2010) also studied SA in VTS operators using an applied cognitive task analysis (ACTA) to understand how VTSOs use available information for decision-making (Brödje et al. 2010). Conclusions from this work indicate that VHF communications are crucial in building SA, that VTSOs prefer radar to AIS as an information source, and that additional information sources including sensors might help build SA but are not critical for decision-making (Brödje et al. 2010). In further work, they also developed a model that represents the selectiveness of information sharing between VTSOs and vessels in the form of a filter which is made up of pattern recognition, trust, deviation from norm, protocol, and role (Brodje et al. 2013). This model showed that the VTSOs only account for certain pieces of information from their information sources to communicate with vessels, and this varies from vessel to vessel and operator to operator (Brodje et al. 2013). These findings exemplify the complexity of the VTS station and show that information processing is non-linear and affected by many factors. Further, this work tried to better understand miscommunication within VTS operations and reiterated the importance of VHF radio as the major source of communication between ships and shore and a critical source for building a mental model of the traffic situation (Brodje et al. 2013).

Nuutinen et.al described the VTS as a complex socio-technical system and discussed the past, current, and future challenges for VTS development (Nuutinen et al. 2007). This study complemented other VTS research which highlighted that VTS systems vary significantly in their outcome, practices, and understanding of core tasks, based on their geographical location and competent authority (Nuutinen et al. 2007; Brödje 2012; Praetorius 2014; Praetorius et al. 2015b). These practical and organizational differences are attributed to the fact that there is no international legislation regulating VTS which can cause tension and misunderstanding between various actors within the maritime socio-technical system (Brodje et al. 2013; IALA 2016). SOLAS Chapter V (Safety of Navigation) Regulation 12 entered into force in July 2002 and provides vague performance-based guidelines for VTS operations. These guidelines place responsibility on competent authorities to undertake and arrange the organization and responsibility of VTS services, inadvertently leading to major differences between geographical locations (Praetorius 2014). These differences range from the amount of traffic in the designated port, to organizational differences of having only one VTSO in smaller more local areas, to several operators with specific tasks and activities (Praetorius et al. 2015b). Costa et al. observed VTSOs at the Swedish Maritime Authority (SMA) to understand non-technical factors in communication and general work practices (Costa et al. 2018a, b). This study identified VTS role ambiguity, meaning the VTSO role boundaries shift as a consequence to the lack of prescriptive regulations governing VTS operations, leading to many inconsistencies in work practices among VTSOs (Costa et al. 2018a, b). Further, as noted by Praetorius et al., these major operational differences between and within VTS stations are of great importance when changes (i.e., procedural, technology, personnel) are implemented at VTS stations (Praetorius et al. 2015b).

1.3 E-Navigation solutions for vessel traffic services

Based on the e-Navigation strategy set by the IMO to increase connectivity, transparency, and digitalization within the maritime sector, several European Union (EU) projects have been completed to assess the impact of advanced technologies and low-level automation within the maritime industry (International Maritime Organization 2014). Conceptualized in a former EU project, MONALISA2.0, the Sea Traffic Management (STM) Project (2014-EU-TM-0206-S) was created. The goals of the STM project are to create a safer, more efficient, and environmentally friendly maritime sector through efficient information exchange, offering a digital infrastructure for shipping. The STM concept is being used in many different projects including efficient flow, implementing efficient port calls using real-time information; real-time ferries (RTF), connecting ferry lines in the Baltic Sea region to the hinterland transport chain making ship voyages a connected part of the transport chain; and STM Balt Safe, increasing safety in the Baltic Sea by providing STM services to tanker traffic in the Baltic (Sea Traffic Management 2018).

This paper focuses on the STM Validation Project and the newly developed information sharing services called the "STM services." The STM services have been developed to exchange information between ship to ship and ship to and shore and promote transparency, safety, and efficiency in the maritime sector. While several STM services developed in the project, only the services listed in Table 1 are evaluated in this study (see http://stmvalidation.eu/stm-services/ for detailed information).

Table 1 Definitions of STM services

STM service	Definition
Ship to shore route exchange	Two situations in which a route may be shared: (1) A ship plans a route to a certain port and sends it to the VTS for "review" and then may receive improved route suggestions, from the VTSO (2) A ship shares its monitored route with the VTS station which can be updated automatically
Chat function	Send and receive text messages between vessels´ STM ECDIS and the STM equipped VTS
Route cross-check	The ability for the VTSO to receive and review a route sent from a vessel. The review consisted of visually checking the route on an electronic chart
Sending route suggestions to ship and shore based navigational assistance	The VTS can send either a new or edited route to a ship with an improved alternative route and/or schedule
Route-based prediction tool	VTS operators can foresee congestions or close quarter situations based on the monitored route and actual speed from AIS
Enhanced monitoring	An alert system which notifies the VTS when a vessel leaves a monitored route based on parameters set by the VTSO

The STM services provide the possibility to visualize and predict the traffic situation on a vessel's ECDIS or a VTS system hours in advance, encouraging a proactive approach to traffic planning. This proactive approach introduces the ability for the VTSO to review vessels' intentions and make contact if necessary, review and send optimized voyage plans, communicate important navigational messages, and have a much clearer overall picture of the current and upcoming traffic situations.

1.4 Purpose of the study

The shipping industry is currently undergoing a transition toward smart shipping and e-Navigation, which has introduced many technical and operational changes at VTS stations. Newly developed information sharing services threaten to disrupt the traditional communication structure in the maritime socio-technical system which has generated a novel research area yet to be explored. As described above, there exists plenty of research on current VTSOs, their work, and the technical development of the services. However, a gap exists in understanding the *human-tech* relationship (coined by Kim Vicente) in how these technological changes will affect the VTSOs and their role as it is understood today (Vicente 2013). These gaps are addressed in this paper using a mixed method approach to understand the impact of the STM information sharing services from the VTSO perspective. The goal is to understand how these services will affect VTSOs and VTS operations from both technical (zoomed in) and socio-technical systems (zoomed out) perspectives. This paper will provide valuable information for European VTS centers that will be affected by the implementation of e-Navigation and, specifically, the STM services. It will also raise awareness in the maritime domain and supplement the existing research on VTS systems and operators.

2 Methodology

2.1 EMSN Testbed

As conceptualized in MONALISA2.0 and advanced in the STM Validation Project, the European Maritime Simulator Network (EMSN) was developed. The EMSN consists presently of 12 connected ship handling simulators based in seven EU countries with the possibility to run scenarios with over 30 manned simulated vessels. The EMSN is a unique testbed that enables the introduction and testing of new technologies in complex and large-scale traffic situations. The EMSN also has the capability to integrate "shore centers" which function as typical VTS stations. The EMSN testbed was used in this study to simulate realistic traffic scenarios with human operators both on the ship bridges and at VTS stations. The scope of this paper is limited to the data from the VTS operators.

2.2 Experimental design

During 2017 and 2018, data were collected over four non-consecutive weeks within the EMSN, each test day consisted of two 1.5-h scenarios, simulating traffic conditions in the southwestern Baltic and the English Channel/Southampton areas. Each geographical area had a respective shore center (VTS). The English Channel scenario area was manned by the Warsash Maritime Academy VTS in Southampton, and the Baltic scenario was manned by the Swedish Maritime Administration (SMA) VTS in Gothenburg, Sweden. The shore center functioned as a typical VTS center with additional access to the STM services.

The Baltic scenario tested dense, close quarters traffic situations representing one of the worlds' busiest traffic corridors with numerous recommended routes, a planned oil spill, junction areas, and crossing ferry routes. The English Channel scenario was created for the South Coast of England with the Port of Southampton representing the major port of interest. The English Channel scenario focused more on port approaches, with less traffic congestion, and allowed for additional time to plan navigation strategies compared with the Baltic scenario.

The first 2 weeks of data collection were baseline tests, meaning VTS operations as they are today without any STM functionality. The last 2 weeks consisted of exactly the same protocol and experimental design, except that the STM services were available to both vessels and the VTS. Although the scenarios were designed to start the same way each test day, the bridges were manned with live operators who made decisions based on their understanding of the situation; thus, the traffic situations unfolded slightly differently each day. For example, ship A on Tuesday might have made a maneuver that led to a congested and tricky situation, while ship A on Wednesday maybe chose a maneuver that removed all future obstacles. Over 500 professional mariners and 16 VTSOs were included in this original data collection. However, this paper presents results solely from the VTS operators.

The familiarization process for the VTSOs was the same at both simulation centers and in both the baseline and the STM simulations. This included a brief introduction to the VTS areas of the exercises with large-scale charts, an explanation of the usual traffic patterns, the overall VTS system, and the STM services, if applicable. The VTS operators were familiar with the simulator systems used in their respective VTS station. The VTSOs were instructed to monitor the traffic and intervene if they detected some unsafe maneuvers from the vessels, just as they would in normal operations. The VTSOs were not given any specific instructions related to the use of the STM services versus traditional communication means, such as VHF. This approach was selected to represent a more realistic situation so that the VTSOs were not forced to use the services and instead would use the services based on their time, ability, and interest. The VTSOs had an instructor available to them at all times during the simulations. The instructor's role was to provide support for technical questions but not to answer any nautical or decision-making related questions.

2.3 Research ethics

Participants were fully informed of the procedures and risks of the experiment and signed electronic and written informed consent prior to the start of the simulations. The experiment complied with the requirements of article 28 of the EU General Data Protection Regulation (2016/679) regarding protection for physical persons in the processing of personal data. Each participant was assigned a unique identification number (ID) prior to arrival, which was used for the questionnaires throughout the study to maintain confidentiality.

2.4 Demographics

During baseline testing, the VTS operators consisted of project members who were familiar with the local geographical areas. Since no new services were being tested, it was decided that new participants everyday were not required. During STM simulations, a total of 16 different VTS operators, 13 men and 3 women participated in the simulations. Eight VTSOs were from Sweden, 6 from the UK, and 2 from Norway. The participants were between 20 and 69 years of age. Years of experience as a VTSO ranged from < 1 year to 11–20 years, with most VTSOs having between 3 and 5 years of experience. The current role of the VTSOs varied: 9 participants currently work as VTS managers, operators, or supervisors; 3 work as pilots; 2 as instructors; 1 as a project leader; and 1 as a captain.

2.5 Data collection

Both observational methods and questionnaires were used to collect the data. The majority of the data was collected using observations from an experienced VTS instructor and paper co-author who observed and recorded all direct interactions between the vessels and the VTS and VTSOs and their equipment. During the baseline simulations, VHF radio was the only available method of communication between the ship and VTS. In the STM simulations, there were several more channels to actively interact with ships including VHF, chat, and route suggestion from shore to ship. The use of these three services is considered *direct interactions with ships*.

In the STM simulations, the VTSOs had three additional tools: enhanced monitoring, route-based prediction, and route cross-check (Table 1) to access information about current and upcoming traffic situations to use for decision support. In this case, the VTSOs were independently using their software to interact with the information shared about a vessel without directly communicating with the vessel. These are referred to as *tools used for planning and predicting traffic*. The observer recorded the frequency of use of these tools and VTSOs completed post-scenario questionnaires about their user experience.

The observer used pre-determined taxonomies (i.e., name of STM service, names of vessels) to populate an excel spreadsheet in order to capture all the data as efficiently as possible. All details about the direct interactions were also recorded including who initiated the interaction, when it occurred, and if there was miscommunication. This information was collected for both Baltic and English Channel scenarios.

The post-scenario questionnaires were collected from the 16 VTSOs who participated in the STM trials. At the end of each testing day, the participants completed a post-scenario questionnaire survey related to the usefulness, impact on workload, and overall impression of the STM services. The surveys were developed using an online survey software Qualtrics (Qualtrics^{XM}, © 2019, Provo, Utah, USA, https://www.qualtrics.com) and consisted of a numerical rating scale with endpoints ranging from 1 to 7.

3 Results

The results are presented in two sections. Section 3.1 presents the results from the observational data which provides a summary of the total usage of STM services and an overview of all direct interactions between ship and shore. Section 3.2 presents the results from the post-scenario questionnaires which provide insight into the user experience of each service.

3.1 Results from observations

This section includes results from the VTS observer positioned at the SMA/Chalmers VTS station throughout the simulations in both English Channel and Baltic scenarios. Although the observer recorded all interactions to the best of his ability, there is always a chance that certain interactions were missed.

Figure 1 provides a comparison between the number of direct interactions between ship and VTS in the baseline (VHF only) and the STM trials (VHF, chat, and route suggestions from shore). In both the English Channel and Baltic scenarios, the total number of interactions increased. A larger increase is observed in the English Channel, which is to be expected because the traffic situation was less intense offering additional time to test the STM services.

Although the total number of direct interactions increased from the baseline (VHF only) simulations to the STM simulations, the VHF communication decreased in both scenarios (Fig. 2). This is very interesting since VHF radio is the pillar of maritime communications between ship and VTS today (Brödje 2012), and a shift to another form of communication could have many consequences which will be discussed in Section 4.

Even though the Baltic and English Channel scenarios were designed very differently in terms of vessel traffic, both scenarios showed similar trends in VHF communications and overall direct interactions. Table 2 provides a summary of who initiated

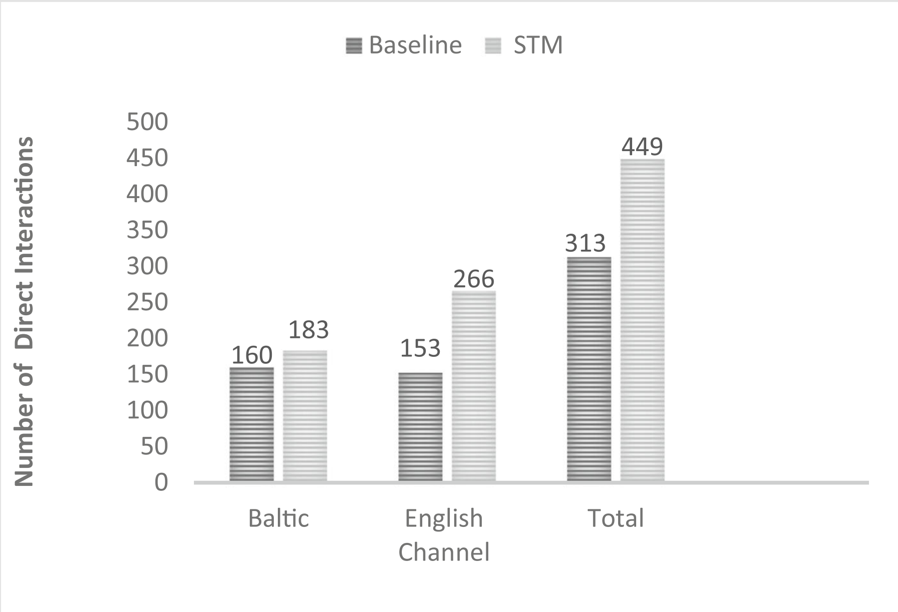

Fig. 1 The number of direct interactions between ship and shore in baseline and STM conditions

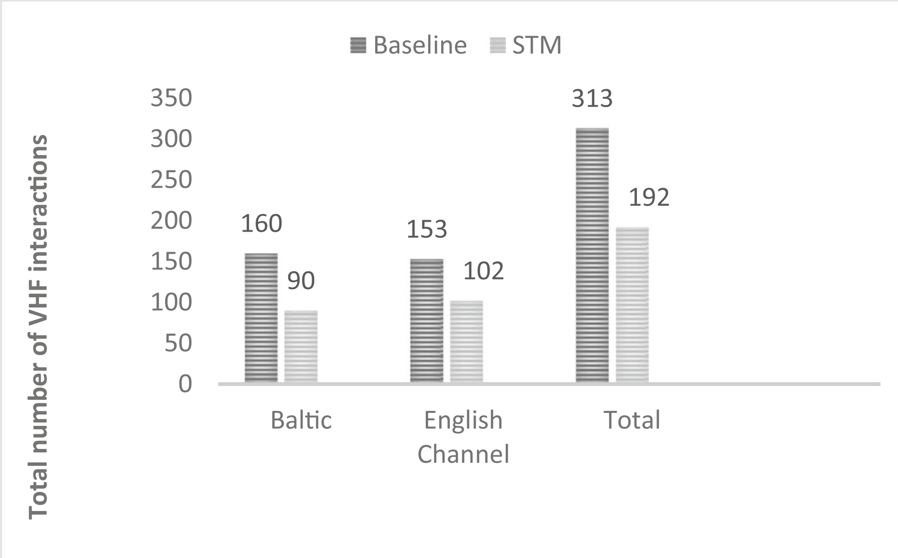

Fig. 2 Total number of VHF interactions in baseline and with STM services

the communications between the ship and the VTSO in both the baseline and STM simulations. The ship initiated the communication approximately the same amount of times in the baseline and STM trials. However, the VTSO initiated the communication approximately twice as much in the STM trials as in the baseline (Table 2). The impact of these results on workload and information exchange will be discussed in section 4.

Table 3 presents the total number of times each service was used in the English Channel (port approach) and Baltic (dense traffic) scenarios. The chat function and route cross-check were the most frequently used services in the English Channel. In the Baltic, the chat function and the route suggestion from shore to ship were used the most frequently but to a lesser extent. In both scenarios, route-based prediction tool and enhanced monitoring were used the least frequently.

3.2 Results from post-scenario questionnaires

Each VTSO completed a post-scenario questionnaire which assessed their experiences using the STM services. Figures 3, 4, and 5 summarize the appropriateness of the information, the workload, and the user-friendliness of the STM services on a scale of 1–7, where 1 = worst imaginable, 4 = fair, and 7 = best imaginable. Figures 3, 4, and 5 are also color coded for easier interpretation starting from darker to lighter shades of red representing a more negative outlook of the services (e.g., worst imaginable is dark

Table 2 Initiation of interaction by either a ship or VTS operator in both baseline and STM simulations

Who initiated interaction?	Baseline	STM
Ship initiated	153	132
VTS initiated	160	317

Table 3 Total usage of each STM service in the English Channel and Baltic scenarios

STM service	English channel	Baltic	Total
Services for direct interaction between ship and shore			
Route suggestion from shore to ship	65	45	110
Chat function	99	48	147
Tools used for planning and predicting traffic			
Route cross-check	81	15	96
Route-based prediction tool	18	11	29
Enhanced monitoring	3	1	4

red), yellow to represent fair/moderate, and various shades of green to represent a more positive evaluation of the services (e.g., dark green is best imaginable). Not all participants used each service, and therefore, the total frequency is sometimes less than 16. It is interesting to note that the lowest rating 1 = worst imaginable, was not selected for any of the questions related to the services.

4 Discussion

Introducing an alternative means of information exchange between ships and shore will affect the maritime socio-technical system (Nuutinen et al. 2007; Praetorius 2014). In order to fully understand these effects, it is helpful to view the situation through

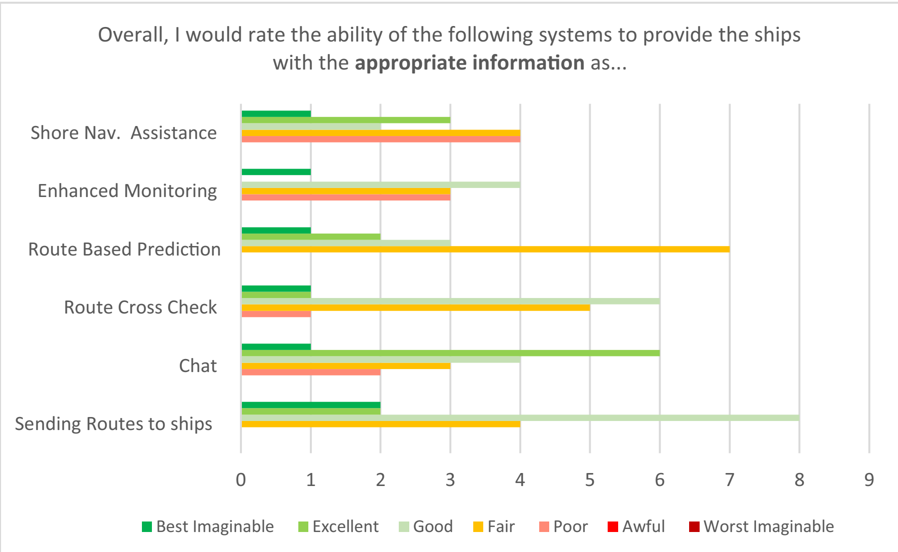

Fig. 3 The frequency distribution of the perceived appropriateness of information provided by the STM services

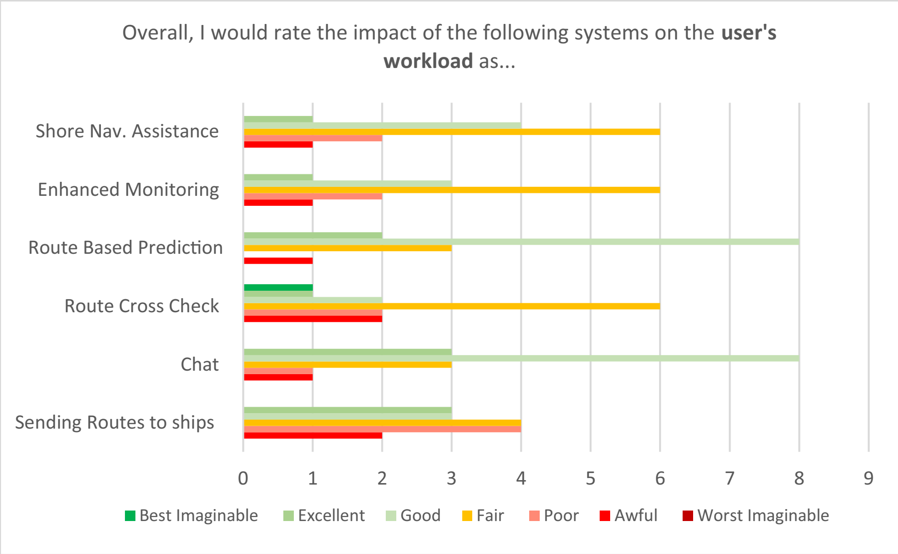

Fig. 4 The frequency distribution of the perceived impact on workload of the STM services

different lenses. It is necessary to examine the effect of each individual STM service and how it might be used from a strategic and tactical perspective (zooming in). Meanwhile, it is also critical to consider how altering current practices of information exchange will affect the entire ship-shore socio-technical system (zooming out). The following section will utilize these two perspectives to discuss the potential impact of the STM services on VTS operations and work practices.

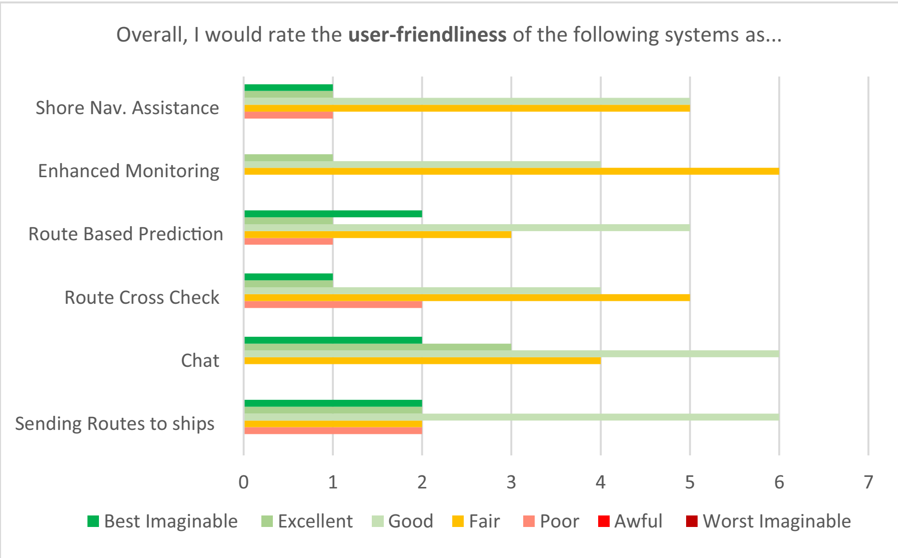

Fig. 5 The frequency distribution of the perceived user-friendliness of the STM services

4.1 Assessment of the STM services

4.1.1 Chat function

The chat function allows sending and receiving written messages between two parties, either ship to ship or ship to shore (VTS). In this paper, the results are only provided between ship and VTSO (and vice versa). The chat function offers a private conversation forum between the two parties, which is drastically different from the only means of communication today, VHF radio. VHF is a public means of communication in which conversations between two parties can be heard by any vessels in the vicinity. Table 3 provides a summary of the chat messages sent and received in both the Baltic and English Channel scenarios. The VTSOs used the chat function a total of 147 times, 99 times in the English Channel and 48 in the Baltic, making it the most frequently used STM service in the simulations.

The chat service was used more frequently in the English Channel than the Baltic, and this can be explained by the purposeful design of the traffic situations. The English Channel traffic was less hectic and allowed additional time for bridge team participants to plan and test the STM services, whereas the Baltic consisted of dense traffic in close quarters not allowing as much time to use chat as a means of communication. The chat function is intended to be used as an alternative means of communication, time permitting, to VHF radio but is not intended to replace VHF radio-based communication. Based on the results of this study, it appears that the VTSO participants used the chat service in accordance with its intended use. It was mostly used to supplement suggested routes sent from the VTSO to the vessels. It was often deemed necessary by the VTSO to explain why the route suggestion was sent, e.g., the route was sent to the vessel to avoid an area. The chat service was also used instead of VHF communication in other matters, e.g., information about location and timing for a pilot pick up.

The post-scenario questionnaire results showed that the participants rated the chat service favorably in terms of providing appropriate information (Fig. 3), the impact on workload (Fig. 4), and the user-friendliness (Fig. 5). This is a controversial finding because it contradicts the results from the ship-bridge test participants as described in the authors previous paper which shows that the chat service generated the most negative feedback, primarily because of its poor usability, and the fact that it distracted the bridge team from looking out the windows and monitoring the navigational instruments (Aylward et al. 2018). It is important to note that the service is designed differently when integrated into a ship's ECDIS than it is in a VTS planning station. This finding emphasizes the importance of usability testing and human-centered design (Costa 2018; Man et al. 2018).

There are many considerations, both positive and negative, related to altering the current method of communication between ship and shore. In general, it is often considered easier for a non-native English speaker to read and understand messages rather than listening over the VHF. Moreover, the chat function allows the messages to be stored and can be reviewed by all members on the bridge for as long as needed. In dense traffic areas, the VHF radio can become chaotic with many vessels trying to communicate over one another, in which case it could be helpful to have another means of communicating a short message. However, many mariners have expressed concern that they could miss out on the agreements or discussions made by the vessels around them which might contain useful information. Previous research has highlighted the importance of listening to this information via VHF radio, in terms of situational awareness, safety, and efficiency (Nuutinen et al. 2007; Brödje et al. 2010; Brödje 2012; Praetorius 2014). Altering this communication structure will have definite consequences on VTS operations and the VTSO mental model of the VTS area; this will be further discussed in section 4.2.2. Some participants in the study also believed that it is simply easier and more efficient to call over VHF radio rather than typing out a message.

Miscommunication The risk of miscommunication must be considered to understand the impact that the chat service and a clear communication of intentions could have on safety. The observers were instructed to listen and record any miscommunication. Miscommunication in this study is defined as *an exchange of information in which the message did not get through or was misunderstood*. This information was difficult to capture, and therefore, if it was not a completely obvious case of miscommunication, it was not recorded.

In the baseline simulations (i.e., VHF only), a total of 313 direct interactions were recorded, and the observer identified 20 cases of miscommunication between a vessel and VTS, rendering a miscommunication rate of 6.9%. The STM simulations had 449 total direct interactions and 11 cases of miscommunication, rendering a miscommunication rate of 2.4%. An example of miscommunication identified during the simulations was the following: vessel A calls vessel B, but vessel C answers, vessel A believes they have an understanding with vessel B, when the agreement was made with vessel C. Clearly, this is a potentially dangerous situation depending on what information was exchanged. Miscommunication was decreased by approximately half with the availability of the STM services. It can be expected that this decrease in miscommunication is mostly attributed to the chat function; however, it is impossible to draw this conclusion based on this limited data.

Unfortunately, miscommunication is a common occurrence in shipping because of the current method of communication between ship and shore, VHF radio (Brödje 2012). This highly depends on the traffic in the area, language and culture on board, and the geographical location in which a ship is sailing. In busy areas, the VHF radio traffic can be very intense which would increase the chance of miscommunication. Miscommunication serves a "breaker of teams," and should these results reflect reality, the STM services could prove to be very helpful in communication efforts at sea (Brödje 2012; Brodje et al. 2013). Miscommunication during information exchange between ship and shore should be carefully assessed in further testing.

4.1.2 Ship to shore route exchange and route cross-check

There are two situations in which a route may be shared from ship to shore: (1) A ship plans a route to a port and sends it to the VTS for "review," the VTSO may accept the route or send an improved route suggestion, and (2) a ship shares its monitored route with the VTS station. In this study, prior to the start of the simulations, the instructors preset every vessel to share their monitored route and schedule (voyage plans) with the VTS station, meaning that option two was the primary situation that ship to shore route exchange service was used. This was decided based on time constraints during the test day. In reality, each vessel would have to make an active choice to share their route with the VTS. Therefore, all 480 voyage plans were sent to the VTS stations and showed up on the VTS displays at different times, making it impossible for the VTSO to sort through all the routes. However, the observer noted that in 96 cases, 81 in the English Channel and 15 in the Baltic, the VTSO clearly performed at least a brief review of the vessels' monitored route during an early stage of the scenario (Table 3). It should be noted that this number is solely based on clear indications to the observer that the VTSO was reviewing the vessel's route (i.e., zoomed in on the route, touched the mouse, moved the centre of the picture, etc.). However, route cross-check might have been completed to an even larger extent, but the observer was unable to clearly identify these actions.

In the post-scenario questionnaire, participants rated the route cross-check service somewhere in the middle of fair (4) and good (5) in terms of appropriate information and user-friendliness, but the results show a more negative outcome in their perception of the potential impact on their workload (Fig. 4). This could be potentially explained by the number of routes presented at once when the simulations began. In reality, this would not be the case, and the routes would be received at different times. However, it is important to consider that this service could have an impact on VTSO workload and is discussed further in section 4.2.2.

An advantage of a vessel sharing their route in advance is that the vessels' intentions can be reviewed to ensure that the vessel has selected a safe route in which all conditions are met (i.e., water depth is sufficient, the proper pilot boarding position has been selected). Today among VTSOs, it is commonly understood that the first contact made with a ship through VHF is a good opportunity to "take the temperature" and check up on the conditions of the crew on board (Brödje 2012). For example, if the OOW on board the ship sounds alert, speaks clear English, reports the information required and at the proper reporting point and time, then, the VTSO is likely to judge the ship as a low-risk vessel. This informal practice may change in the future with e-Navigation, as many non-technical communications are likely to be replaced with automated services (i.e., route sharing in advance). Instead, receiving a route from the vessel could indicate to the VTS that the vessel has a plan which will be checked and monitored by the VTS.

4.1.3 Route based prediction tool

The route-based prediction tool offers the possibility to foresee congestions or close quarter situations based on the vessel's planned route and actual speed. The monitored routes can be displayed on both the planning and monitoring screens in the VTS systems, which allows the opportunity for the VTSO to make predictions based on the vessels' monitored route and speed obtained by AIS information. Using this information, the VTSO can observe and respond to potential situations or congestions much further in advance. The route prediction tool was one of the least used services during the simulations; it was used 18 times in the English Channel and 11 times in the Baltic scenario (Table 3). The post-scenario questionnaire results indicate that this service ranked mostly "good" in terms of user-friendliness, and the potential impact on workload, and mostly "fair" in terms of appropriate information (Figs. 3, 4, and 5).

4.1.4 Sending route suggestions to ship and shore based navigational assistance

The STM services sending route suggestions to ships and shore-based navigational assistance were merged into one category for this analysis. The definition of Navigational Assistance Service is described as any information provided by the VTS to the vessel that aims to assist the vessel in its navigation (IALA 2016). An example of navigational assistance could be that the VTS informs the vessel about a suitable route through a narrow passage and advises of speed limits and any other relevant information. The VTSOs sent route suggestions to vessels a total of 110 times during this study (Table 3). Sixty-five routes were sent in the English Channel scenario, which was expected since the VTSO workload was lower allowing additional time to test the STM services and work in a more proactive manner. Interestingly, 45 routes were sent in the Baltic scenario in dense traffic and congestion, and it was not expected that the VTSOs would have time to use the route suggestion feature. In many cases in the Baltic scenario, routes were sent to direct vessels away from the oil-polluted area, and this had to be completed quickly and with short notice. The presumed first choice would have been to use the VHF radio as a primary means of communication; however, on many occasions, the VTSOs preferred to send a route segment directly to the vessels' ECDIS. This indicates that the feature was appreciated and understood by the VTSOs, as they trusted it enough to communicate important information to vessels in a compromised situation. This is supported by the positive ranking of these services in terms of the appropriateness of information and average rating of user-friendliness in the post-scenario questionnaires (Figs. 3 and 5). The results showed a more negative trend in relation to the perceived impact on workload (Fig. 4).

4.1.5 Enhanced monitoring

The purpose of the enhanced monitoring service is to offer the shipowner (or ship operator) a service that can monitor a particular vessel through the whole voyage or certain parts of it. The vessel must first share its intended route, and the system will monitor when/if the vessel leaves its monitored route. The VTSO must set cross-track distances associated with the vessels intended route that are considered a "safe zone". If the vessel is outside the preset cross-tracks, an alarm will sound which alerts the VTSO of the situation. The VTSO can then contact the vessel and ask for an explanation and potentially receive the new intentions of the vessel. Automated enhanced monitoring has the potential to substantially expand the size of today's VTS areas. Expanding the continuously monitored areas at sea or introducing automated monitoring that could alert the VTSO of strange vessel activity would be a proactive measure to reduce accidents and promote cost savings.

The enhanced monitoring service was only used for a total of 4 times in both scenarios, making it difficult to draw any user-based conclusions about the service. It is interesting to note that participants *believed* they used the service, as 11 out of 16 participants evaluated it in the post-scenario questionnaire. The VTS instructor explained that this is possible because they were continuously "enhancing" their monitoring through using all the services, and it is possible that they misunderstood that this was itself a service. Based on the available results and informal discussions with VTSOs, this service was infrequently used because of the lack of familiarization time prior to the simulations and the fact that it requires continuous attention from the VTSO which was not feasible in these scenarios.

4.2 Socio-technical system perspective

Thus far the discussion has focused on each individual STM service and its possible impact on the VTSO and one or more vessels. However, it is also critical to assess the impact of information sharing services on the entire ship to shore relationship using a holistic systems approach (zooming out). The next section will provide a general overview of how the introduction of new information sharing services (i.e., STM services) may affect and potentially disrupt current communication practices in the maritime socio-technical system.

4.2.1 Change in overall direct interactions

In the baseline scenario, VHF radio was the only means of interaction available between ship and shore. In the STM scenarios, VHF radio, chat, and route suggestions from shore were available. The overall VHF communication decreased in both scenarios (Baltic and English Channel) when the STM services were introduced. However, the number of direct interactions between the ship and the VTSO increased with the availability of the STM services (Fig. 1). These results were observed in both scenarios; however, the English Channel scenario caused a much larger increase in interactions. It is hypothesized that this is because the scenario was designed with less traffic to represent a situation with time to plan in advance, thereby providing the opportunity for the VTSO to be proactive, one of the main objectives of the STM services. Additionally, the VTSO initiated the majority of the interactions (Table 3) which might mean that the VTSOs were able and willing to provide additional information to the ships to assist with decision support. Although these results are not surprising given the additional means to interact (i.e., STM services), an increase of interactions between ship and shore at this magnitude may have wider implications.

4.2.2 Workload

Workload has been thoroughly studied in other transportation industries, namely, aviation for both pilots and air traffic controllers (ATC) (Wickens 2002; Parasuraman et al. 2008; Parasuraman and Wilson 2008). Although the regulatory and legal frameworks differ significantly from ATCs to VTSOs, there are many similarities (i.e., dynamic work tasks, safety critical performance, communication, and trust) between the two professional roles and lessons to be learned from the implementation of automation in aviation (Brödje 2012; Praetorius 2014).

The observed increase in direct interactions between ship and shore and the post-scenario questionnaire results indicates that the STM services will have an impact on the VTSO workload. The question related to workload was the only one that triggered “awful” as a response in relation to the services (Fig. 4). The VTSO will be more involved in the traffic situations with the added information exchange services (both direct interaction services and tools used for decision support, planning, and predicting traffic) compared with traditional navigation. The concepts of workload and SA are interrelated, and the impact on human performance will vary with the level and type of automation introduced into a work task (Endsley 1999a, b; Wickens 2002). In the current study, the level of automation is low and consists of information acquisition and information analysis, also sometimes known as *information automation* (Parasuraman et al. 2000). The STM services provide more information automatically to the user without making a decision selection or action implementation (Parasuraman et al. 2000). Generally, the purpose of this type of automation is to augment the human operators' perception and cognition; however, this is not always achieved as more information does not necessarily mean a better SA (Parasuraman et al. 2000). Adding information to an operators' task can lead to information overload and can also consequently negatively impact situation awareness (Endsley 1999a, b).

Increasing workload or work tasks could also impact manning requirements and system design at VTS stations. In late 1980s aviation research, the decision to downsize the flight deck crew from three to two members by eliminating the flight engineers position onboard was based on a full year of observations and data collection forming a detailed workload analysis (Parasuraman et al. 2008). In the case of the VTS, it could result in adding another VTSO depending on the amount of added work. For example, the VTSO will have the opportunity to complete a route cross-check well in advance before the vessel enters a VTS area. Then, time permitting, the VTSO will review and accept or reject and resend a route. If rejected, the route can be edited by the VTSO and sent back as a suggestion to the ship. If the ship agrees with the VTS, they confirm the route, switch it to "monitoring," and the VTSO has a much less stressful situation when the vessel enters a VTS area. However, in a port with continuous dense traffic, this might be challenging, and this task should potentially be performed by another VTSO. A more detailed workload analysis is required to determine whether or not the current manning requirements are sufficient for new information sharing services.

Compared with current navigation practices, route sharing and review can be completed hours in advance, reducing stress upon arrival in port and potentially increasing safety. These factors must be considered when trying to understand the overall impact on the VTS work practices. It has been established that the work tasks will increase for VTSOs; however, it is important to recognize the experimental design of the simulated scenarios. Each scenario was only 1.5 h in duration, meaning the VTSO and the vessels were dropped into an area and the work commenced all at once. In reality, information sharing between ship and shore using the STM services would be continuous, and the work would be distributed more optimally so that the VTSO can observe, intervene, and share information much earlier in advance. Therefore, it is possible that the workload might even decrease in the immediate VTS area. Moreover, it could be argued that the additional sources of relevant information and the holistic view of the traffic situation could contribute to a better SA. This will also depend on the training and familiarization of the VTSO using the STM services.

The STM services provide the opportunity to visualize the traffic situation hours in advance, encouraging a proactive approach to safety. However, certain tasks or responsibilities (i.e., route planning) might be shifted from the bridge to the VTS. Based on the results, it is difficult to fully assess the extent that the STM services, or similar will impact the workload for VTSOs. The goal is to try to understand how to exploit the workload-reducing advantages of automation while still keeping the user "in-the-loop" on both the ships bridge and at the VTS station (Wickens 2002).

The participants were generally positive toward the further development and integration of the services. However, because this study was conducted in a controlled simulated environment, there are many factors to consider that must be further investigated to fully understand how the STM services will impact the overall operations in functioning VTS stations. Workload and SA are two areas that must be further explored to ensure that proper measures are taken to account for any unwanted consequences in work practices.

4.2.3 Communication

Presently, VTSOs use VHF radio, radar, AIS, and CCTV as their primary sources of information to create a mental model and achieve good situation awareness, which is critical for their job (Brödje et al. 2010). In terms of the priority of information sources, Brödje et al. (2010) found that VTSOs assign a much higher value to information received over VHF radio, compared with other sources of information (i.e., meteorological and hydrographical sensors, databases) (Brödje et al. 2010). VHF radio is used to share information to vessels in the fairway, and it is also used for obtaining information about ongoing traffic situations through listening in on VHF communication between vessels (Brödje et al. 2010; Brodje et al. 2013). Previous research has described that the importance of VHF radio is not only about what is being explicitly discussed, it is about how the message is being communicated, which is used to obtain an impression of the situation on the bridge of a vessel and status of the crew (Brödje et al. 2010).

Based on the results from this study, this pattern of communication and major reliance on VHF radio may change with the implementation of additional information sharing services. As observed in Fig. 2, the total amount of VHF communication decreased by approximately 40% from the baseline to the STM simulations with similar results in both traffic scenarios. The STM services offer new means of direct information transfer between ship and shore, which participants clearly used when available. Based on discussions with VTSOs, there are several reasons why an alternative means of communication might be used: (1) a chat message may be considered more efficient than oral communication in certain situations (i.e., the VTSO can send a route directly to the vessels ECDIS accompanied by a chat message rather than explaining it over VHF); (2) in terms of route sharing, the VTS may have received and reviewed the vessel's intended route and may therefore have no reason to ask for the vessels' intentions over VHF; and (3) vessels sharing routes with each other may not need to clarify intentions as frequently if they are satisfied with the route provided.

However, since VHF radio is the foundation of communication between ship and shore today, it is important to recognize and understand how this could affect the entire socio-technical system. All existing research in the VTS domain has focused on the importance of VHF radio and clear communication as indicators of successful navigational assistance (Brödje 2012; Praetorius 2014; de Vries 2015). Implementing additional sources of communication and information sharing in the form of new technologies can have unintended effects on the current non-standardized and location-dependent systems (Praetorius 2014; Costa et al. 2018a, b). As discussed by Praetorius et al. (2015a, b), the current organization of different VTS stations varies significantly which means the use of the STM services or other information sharing services would more than likely differ greatly between VTS locations (Praetorius et al. 2015b). If the

STM services, or similar, are to be integrated at a large scale and used in maritime operations, procedural or legislative guidelines should be updated to regulate and address the safe use of these type of services. The potential danger exists when some vessels and VTSOs are “in-the-loop” and others are “out-of-the-loop,” especially in relation to VHF agreements between ship and shore, and ship to ship. Baldauf et al. (2019) also highlight the importance of addressing communication from an operational and procedural perspective for future “mixed” (i.e., unmanned remote controlled ships and conventional ships) traffic scenarios, after finding it was one of the most important factors for participants in a simulation-based study. They even propose a draft concept of potential communication lines for future traffic scenarios involving autonomous vessels and conventional ships (Baldauf et al. 2019). It is difficult to fully understand the magnitude of these potential situations; however, it is clear that further research must be completed focusing on the work practices for VTS or shore-based operators.

5 Limitations

In terms of generalizability of the results, VTS centers operate differently in ports across the world, and these national differences include varying levels of authority and service provisions. For example, in Sweden, the VTS operates in an information-only capacity, whereas in some other countries, it functions as an extensive traffic management service, more similar to air traffic controlling. Therefore, although the results of this study may be interesting for various geographical locations, it is important to remember the different legislation surrounding each individual VTS station and how that might impact the results. Moreover, this study was completed in a simulated environment which limits the generalizability of the results. Given the current state of the STM technology, this was the safest and most valid method to test the services in a maritime context.

There are endless possibilities for new technologies to enhance information sharing in the maritime context. This study is limited to an evaluation of the STM services which are just some of many possible future solutions for improving maritime safety. It is possible that the role and function of the VTS could evolve much differently than described in this paper.

All participants in this study were first time users of the STM services, and it was therefore difficult to fully assess workload, usability, or usefulness because of the limited duration of the study. Future studies should consider longer familiarization and simulation sessions which would provide needed insight into the feasibility of the services in practice, without the initial steep learning curve. Finally, because the VTSOs were so busy during the simulations, it was impossible to capture their thought process during the scenarios. It was only possible to subjectively record their actions and ask questions post-simulation.

6 Conclusions

The STM services were developed as a solution to the IMO’s e-Navigation strategy, to harmonize, collect, and exchange electronic information between ship and shore for a safer maritime environment. The aim of this paper was to provide insight into the use of these services within the VTS and try to understand how they might affect VTS operations within the maritime socio-technical system. Results showed that the overall frequency of direct interactions between the ship and VTS increased from the baseline testing to the STM simulations, altering the current interaction patterns between the ship and VTS. It can be expected that the method of communication will shift from predominantly VHF radio to electronic STM services (i.e., chat messages, route exchange). However, the results indicate that the traffic situation (i.e., dense or light) will dictate the frequency of usage of the services, as they appear to be more useful in lighter traffic situations with time to plan, than in dense, close quarters traffic situations. This is to be expected as the services were designed for long-term traffic planning and are not supposed to replace current navigation practices. The questionnaire results suggest that VTSOs are generally satisfied with the information provided, and the usefulness of most of the STM services, although the impact on workload must be further investigated.

The STM services encourage a proactive approach to safety. The results of this study align with previous research which highlights communication and miscommunication as critical factors in successful VTS operations (Brödje 2012; Brodje et al. 2013). The results showed a decrease in miscommunications between the VTSO and a vessel when using the STM services, which is attributed to the fact that the chat service provided more successful closed-loop communications. Decreasing miscommunications is thought to be one of the most important advantages of the STM services. However, the observed shift in communication pattern and change in workload could also have an unintentional negative impact on SA and information overload for VTSOs (Brödje 2012; Costa et al. 2018a, b). Therefore, it is important to further study the communication patterns between ship and shore to understand how workload, training, and procedures in the VTS station will be affected by STM or similar e-Navigation services.

The exponential speed of technology development makes it difficult to anticipate what the future of maritime operations will look like. The promise of artificial intelligence, big data, and autonomous vessels may completely change the role of VTS operators and the shore to ship relationship. However, in the current to near future, the STM services or similar are the solution, and this paper has highlighted some of the potential considerations throughout this period. Several VTS centers have already reached out to project members in search of project results for advice about how to handle this transition. This paper provides valuable information for European VTS centers that will be affected by the implementation of e-Navigation and, specifically, the STM services. It also raises awareness in the maritime domain that further research is needed to understand how e-Navigation and automation will affect the day-to-day operations of shipping and how we, as an industry, should manage this in the safest possible way.

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References

Aichhorn K, de Bedoya CD, Berglez P, Cabeceira ML, Troger M, Kemetinger A, Ion (2012) Maritime volumetric navigation system. In: Proceedings of the 25th International Technical Meeting of the Satellite Division of the Institute of Navigation, pp 3651–3657

Aylward K, Weber R, Lundh M, MacKinnon SN (2018) The implementation of e-navigation services: are we ready? International conference on human factors. T. R. I. o. N. Architects, London

Baldauf M, Wiersma E (1998) Risk recognition and collision avoidance by VTS operators. IFAC Proc Vol 31(26):239–244

Baldauf M, Fischer S, Kitada M, Mehdi R, Al-Quhali MA, Fiorini M (2019) Merging conventionally navigating ships and MASS - merging VTS, FOC and SCC? TransNav, Int J Marine Navig Saf Sea Transp 13(3):495–501

Brödje A (2012) Hello, is there anybody out there - just nod if you can hear me. C. U. o, Technology

Brödje, A., M. Lützhöft and J. Dahlman (2010). The whats, whens, whys and hows of VTS operator use of sensor information. International conference on human performance at sea, Glasgow. University of Strathclyde, Glasgow

Brodje A, Lundh M, Jenvald J, Dahlman J (2013) Exploring non-technical miscommunication in vessel traffic service operation. Cogn Tech Work 15(3):347–357

Chang, S.-J. (2004). Development and analysis of AIS applications as an efficient tool for vessel traffic service. Oceans' 04 MTS/IEEE Techno-Ocean'04 (IEEE cat. No. 04CH37600), IEEE

Costa NA (2018) Human-centred design for maritime technology and organizational change, Maritime Human Factors Research Unit, Department of Mechanics and Maritime …

Costa NA, Lundh M, MacKinnon SN (2018a) Identifying gaps, opportunities and user needs for future E-navigation technology and information exchange. Springer International Publishing, Cham

Costa NA, Lundh M, MacKinnon SN (2018b) Non-technical communication factors at the vessel traffic services. Cogn Tech Work 20(1):63–72

de Vries L (2015) Success factors for navigational assistance: a complementary ship-shore perspective. Proc Hum Fact Ergon Soc Eur 175–186

de Vries L (2017) Work as done? Understanding the practice of sociotechnical work in the maritime domain. J Cogn Eng Decis Mak 11(3):270–295

Endsley MR (1995) Toward a theory of situation awareness in dynamic systems. Hum Factors 37(1):32–64

Endsley MR (1999a) Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics 42(3):462–492

Endsley MR (1999b) Situation awareness in aviation systems. Handb Aviat Human Fact:257–276

Harre I (2000) AIS adding new quality to VTS systems. J Navig 53(3):527–539

IALA (2016) Vessel traffic services manual. Interntaional Association of Marine Aids to Navigation and Lighhouse Authorities, Saint Germain en Laye

IMO (2020) Sub-committee on NSCR 7th session, 15–24 January 2020 I. International Maritime Organisation. www.imo.org

International Maritime Organization (2014) The e-navigation strategy implementation plan (SIP). MSC 94. IMO, London

International Maritime Organization, I (1997) IMO resolution a. 857(20) guidelines for vessel traffic services. I. M. Organisation, London

Leavitt HJ (1965) Applied organizational change in industry, structural, technological and humanistic approaches. Handbook of organizations 264

Lützhöft M (2004) "The technology is great when it works" : maritime technology and human integration on the ship's bridge. 907 doctoral thesis, comprehensive summary. Linköping University Electronic Press

Mallam SC, Lundh M (2016) The physical work environment and end-user requirements: investigating marine engineering officers' operational demands and ship design. Work-a J Prev Assess Rehab 54(4): 989–1000

Man Y, Lützhöft M, Costa N, Lundh M, Mackinnon S (2018) Gaps between users and designers: a usability study about a tablet-based application used on ship bridges

Nuutinen M, Savioja P, Sonninen S (2007) Challenges of developing the complex socio-technical system: Realising the present, acknowledging the past, and envisaging the future of vessel traffic services. Appl Ergon 38(5):513–524

Parasuraman R, Wilson GF (2008) Putting the brain to work: neuroergonomics past, present, and future. Hum Factors 50(3):468–474

Parasuraman R, Sheridan TB, Wickens CD (2000) A model for types and levels of human interaction with automation. IEEE Trans Syst Man Cybern A Syst Hum 30(3):286–297

Parasuraman R, Sheridan TB, Wickens CD (2008) Situation awareness, mental workload, and trust in automation: viable, empirically supported cognitive engineering constructs. J Cogn Eng Dec Mak 2(2): 140–160

Porathe T, Lützhöft M, Praetorius G (2012) What is your intention? Communicating routes in electronic nautical charts. Proc Soc Behav Sci 48:3266–3273

Praetorius, G. (2014). Vessel traffic service (VTS) : a maritime information service or traffic control system? : understanding everyday performance and resilience in a socio-technical system under change Doctoral thesis, comprehensive summary, Chalmers tekniska högskola

Praetorius G, van Westrenen F, Mitchell DL, Hollnagel E (2012) Learning lessons in resilient traffic management: a cross-domain study of vessel traffic service and air traffic control. HFES Europe chapter conference Toulouse 2012, HFES Europe Chapter

Praetorius G, Hollnagel E, Dahlman J (2015a) Modelling vessel traffic service to understand resilience in everyday operations. Reliab Eng Syst Saf 141:10–21

Praetorius G, Kataria A, Petersen ES, Schroder-Hinrichs JU, Baldauf M, Kahler N (2015b) Increased awareness for maritime human factors through e-learning in crew-centered design. In: Ahram T, Karwowski W, Schmorrow D (eds) 6th International Conference on Applied Human Factors and Ergonomics. 3: 2824–2831

Sea Traffic Management (2018) About Sea Traffic Management. Retrieved 20 August, 2018, from http://stmvalidation.eu/about-stm/

van Breda L (2000) Capability prediction: an effective way to improve navigational performance. J Navig 53(2):343–354

van Breda L, Passenier PO (1998) Effect of path prediction on navigational performance. J Navig 51(2):216–228

van de Merwe F, Kähler N, Securius P (2016) Crew-centred Design of Ships – the CyClaDes project. Transp Res Proc 14:1611–1620

van Westrenen F, Praetorius GJC, Technology and Work (2014) Maritime traffic management: a need for central coordination? 16(1):59–70

Vicente KJ (2013) The human factor: revolutionizing the way people live with technology. Routledge

Wickens CD (2002) Situation awareness and workload in aviation. Curr Dir Psychol Sci 11(4):128–133

Wiersma JWF (2010) Assessing vessel traffic service operator situation awareness